The Randomized z-Buffer Algorithm

Interactive Rendering of Highly Complex Scenes

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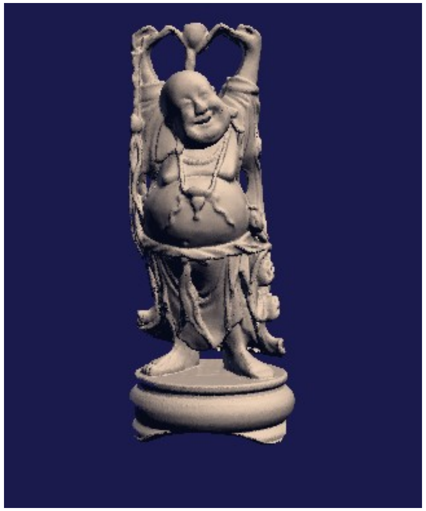
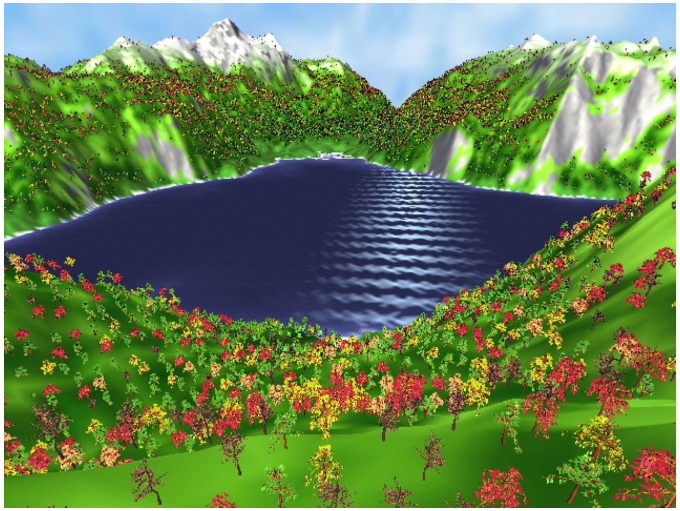
Introduction

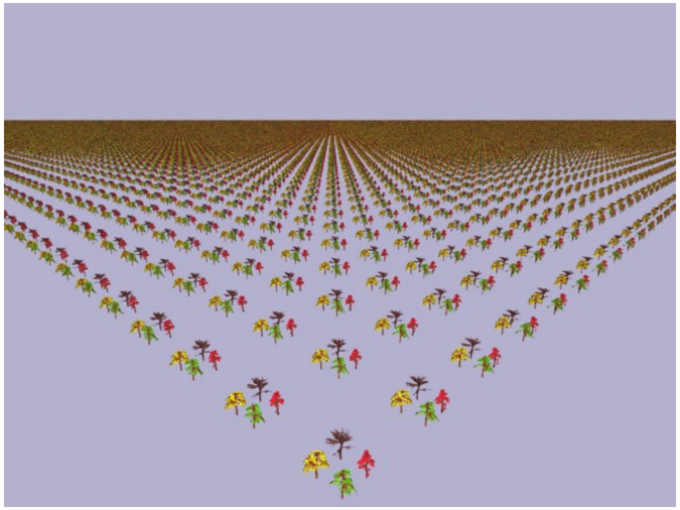
Scene Complexity



10^6 triangles



10^8 triangles



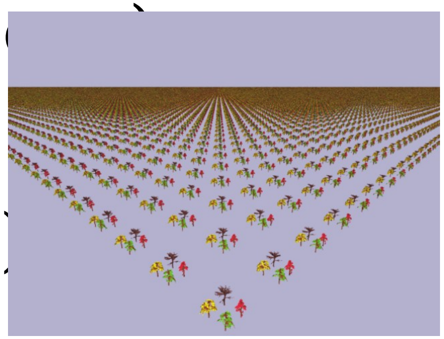
10^{14} triangles

Highly detailed scenes:

- Visualization, Games, CAD, ...
- Interactive walkthrough, editing
- Efficient rendering needed

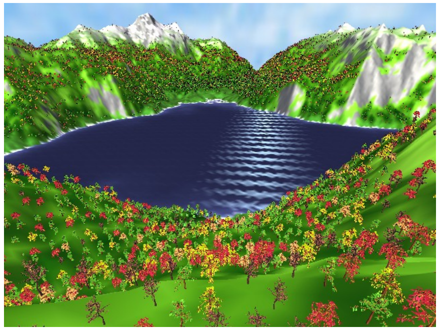
Output-Sensitive Rendering

Complexity parameters: (triangle sc



- Number of triangles: n
- Projected area (visible + occluded)

Z-Buffer-Algorithm:

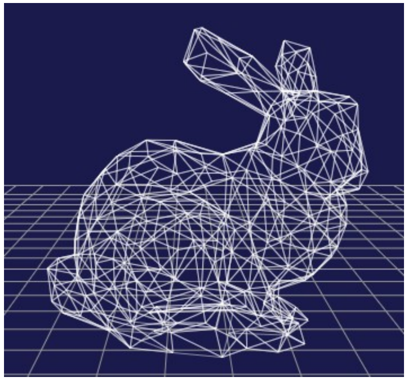


- Rendering time $\Theta(n + a)$
- Not suitable for large scenes

Conclusion:

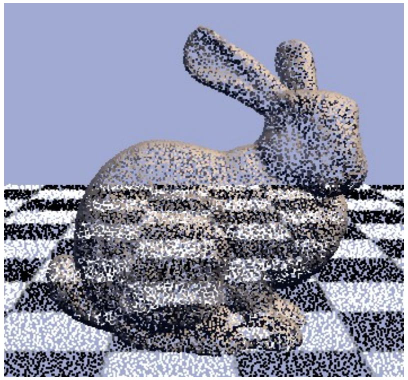
- We need output-sensitive algorithms
- Weak dependence of rendering time on scene complexity

Randomized z-Buffer



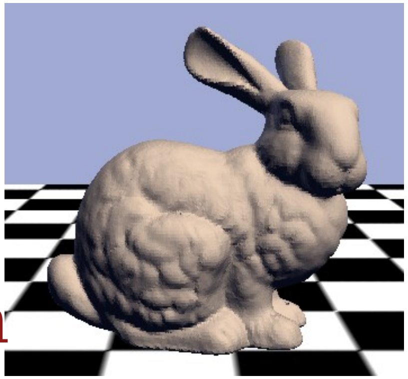
triangles

sample point selection



sample points

image recon-struction



bitmap

Outline of our algorithm:

- Select sample points dynamically, approximately uniformly distributed on the projected areas of the objects
- Reconstruct an image out of the sample points

Running time: $O(a \cdot \log n)$

Related Techniques

Multi-resolution point sample rendering:

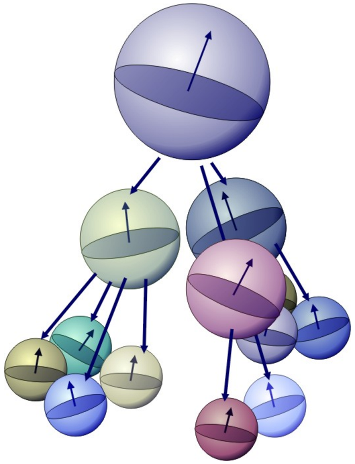
- QSplat [Rusinkiewicz, Levoy 2000]
- Surfels [Pfister et al. 2000]

Approach:

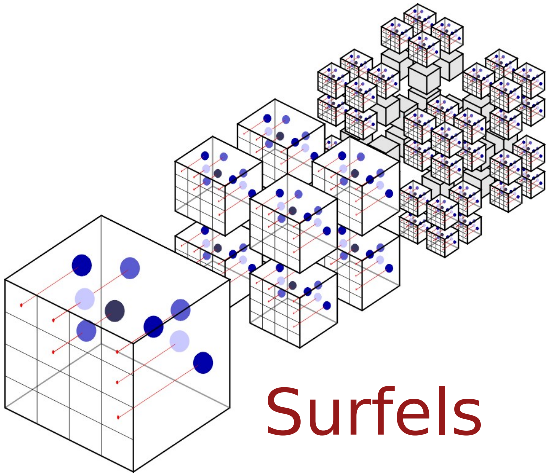
- Precomputed hierarchy of point samples

Open problems:

- Fixed resolution
- Memory consumption
- Dynamic updates are expensive



Qsplat



Surfels

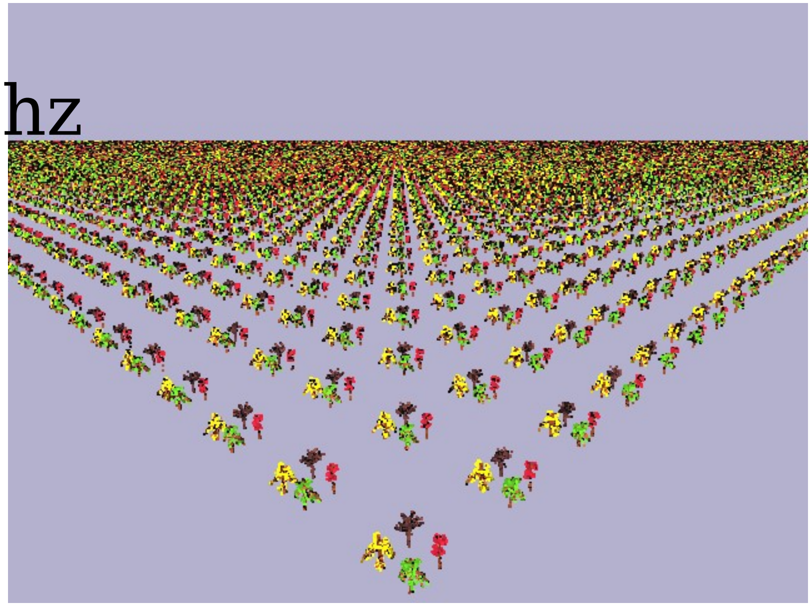
Our Contribution

Randomized z-buffer:

- Fast on-the-fly generation of sample points
- Sampling time $O(a \cdot \log n)$ with $O(n)$ storage
- Efficient dynamic scene modifications
- Fallback to hardware z-buffer rendering for large triangles

Example: (800Mhz PC)

- 10^{14} triangles
- Sampling time: 4.3 sec
- Rendering time: 0.4 sec



Randomized z-Buffer: Image Reconstruction

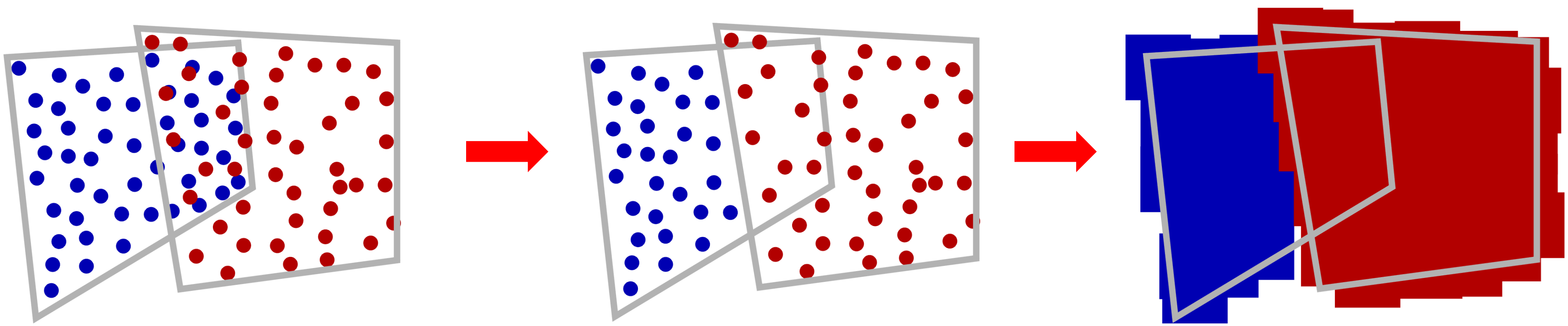
Image Reconstruction

Two problems:

Sample points

1. Reconstruction of occlusion

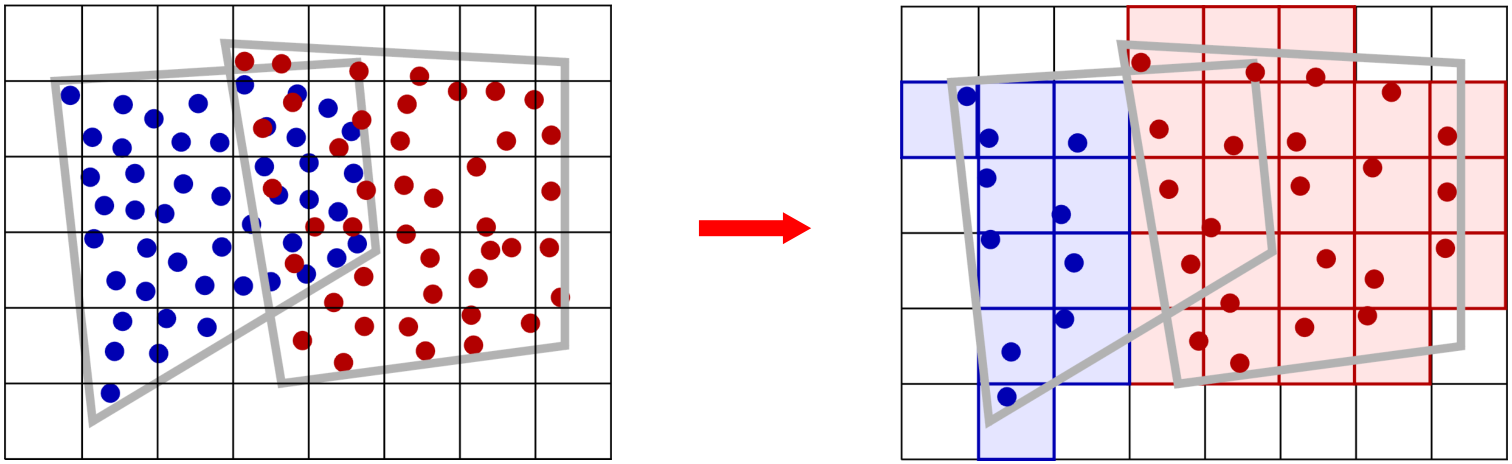
2. Filling



Remove adjacent points with larger depth

Scattered data interpolation

Per-Pixel Reconstruction



Per-pixel reconstruction:

Draw sample points into z-buffer

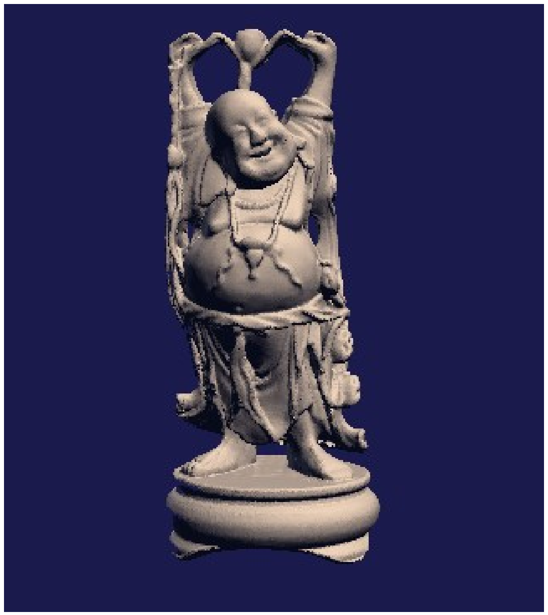
To cover all foreground area: $a \cdot \ln v$ sample points

a - Projected area (visible *and* occluded) [pixels]

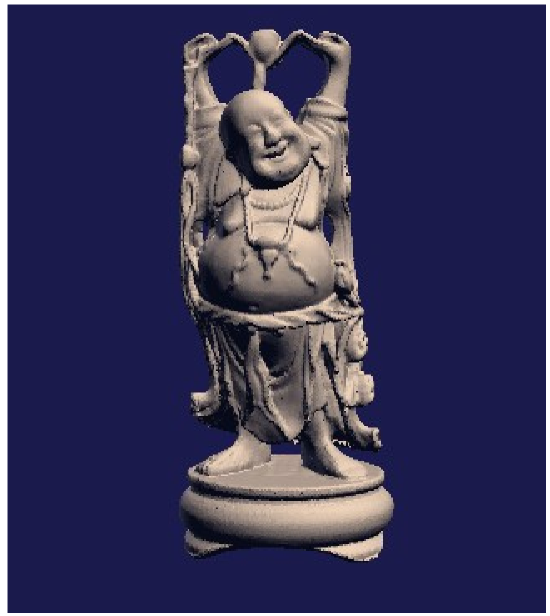
v - *Visible* projected area [pixels]

Splatting

Splatting: Draw colored splats of constant depth



$d = 1$
(110 msec)



$d = 2$
(30 msec)

$d = 5$
(7 msec)

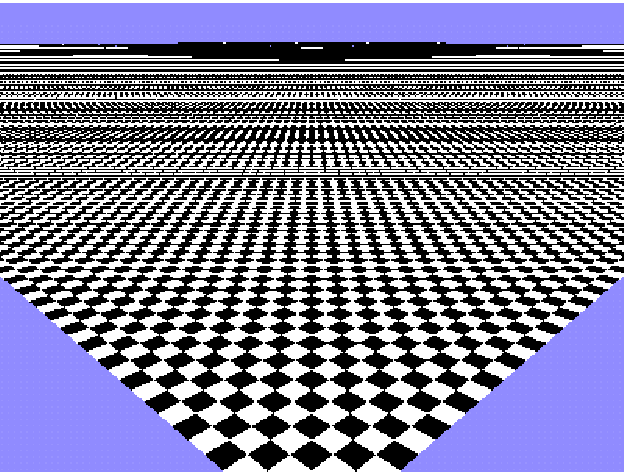
(d = splat size)

Gaussian Filtering

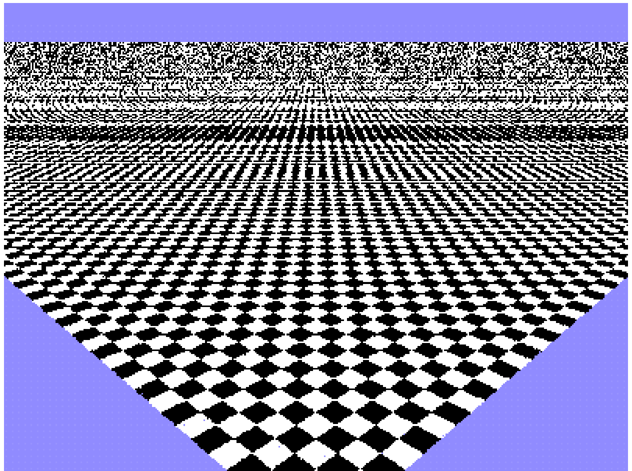
Gaussian Reconstruction:

- Use weighted averages in filling step
- Removes noise & aliasing
- Non-interactive reconstruction times (1-2 minutes)

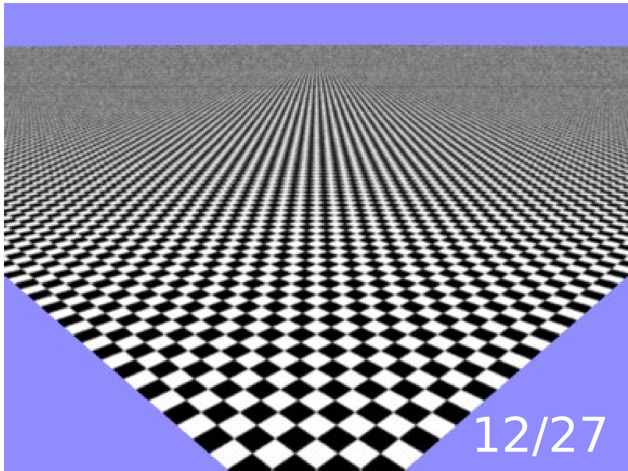
z-Buffer



Per-pixel reconstruction



Gaussian reconstruction



Choosing Sample Points

Projection Factor

Goal: Sample points uniformly distributed on the objects in the image plane

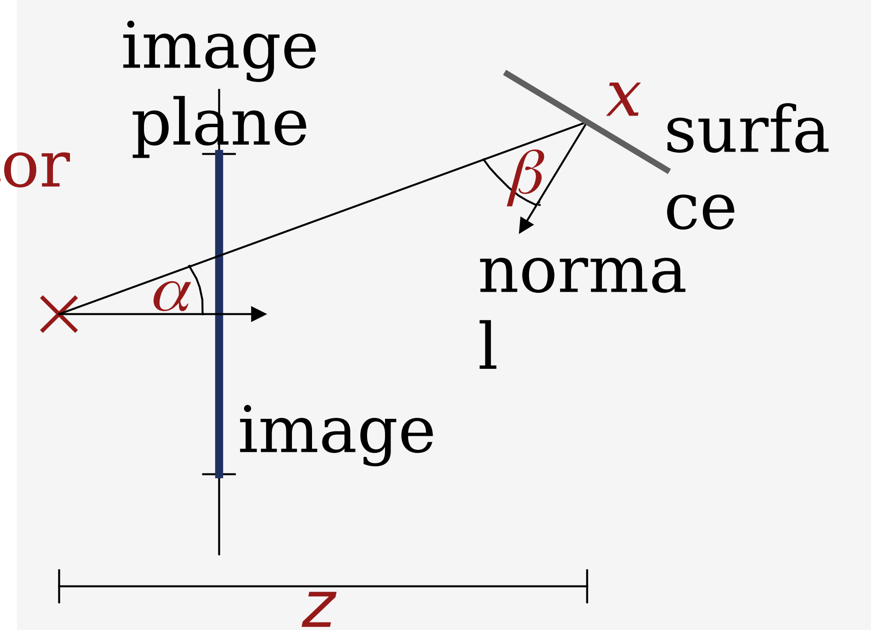
Projection factor: Factor by which an area fragment is scaled during perspective projection

depth factor

orientation factor

$$prj(x) = \frac{1}{z^2} \cdot \cos\beta \cdot \frac{1}{\cos\alpha}$$

distortion factor



Approximation (1)

Chose sample points: Projection factor as probability density in the view frustum

Efficient solution: Approximation algorithm

Idea: Approximation of the ideal distribution

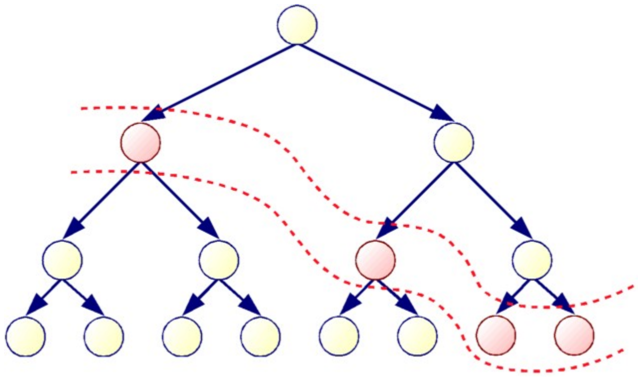
- Do not fall below minimum sampling density
- Exceeding the ideal sampling density leads to longer rendering time “only”

Approximation (2)

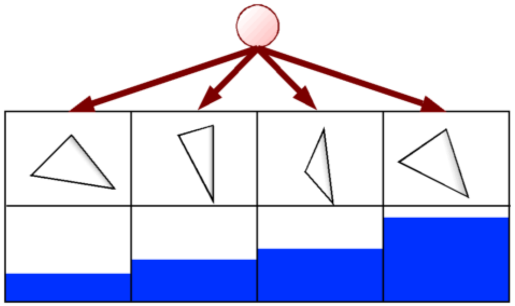
Approximation strategy:

- Precomputed hierarchical clustering of objects
- Online: choose groups of similar projection factor, calculate maximum projection factor
- In each group: distribution by unprojected area

Choosing Groups



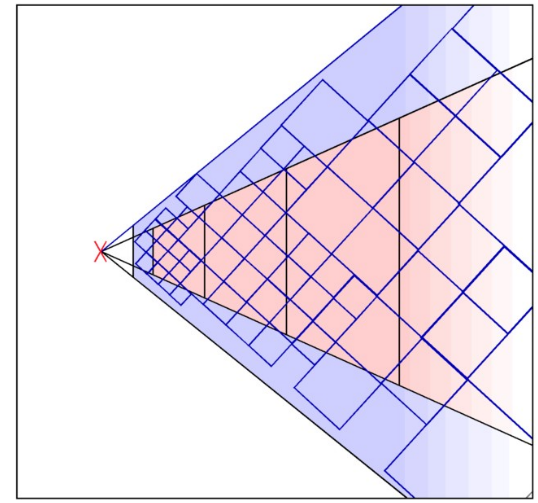
Choosing Triangles



Grouping Objects

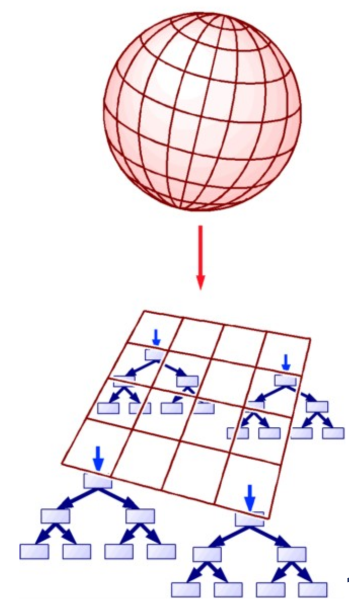
Spatial classification:

- Precomputed octree
- Choose boxes, in which $1/z^2$ does not vary by more than a constant
- $O(\log \tau)$ time, τ = minimal viewing distance / scene diameter



Classification by orientation:

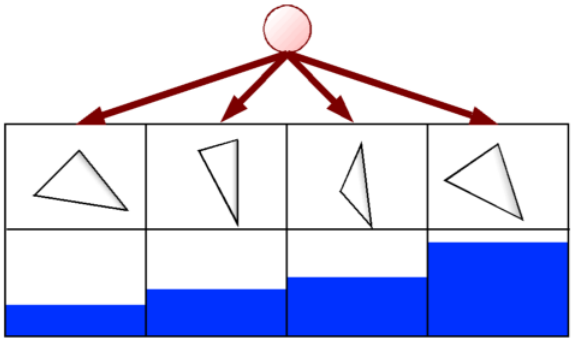
- Orientation classes
- Useful in special cases only



Analysis: neglect orientation factor

- Uniformly distributed surface normals
  $\Rightarrow$ overestimation factor = 4

Selection by Unprojected Area



Precomputation: Distribution List

- List of cumulated area values

Dynamic triangle selection:

- Chose random number uniformly from [0, *maxarea*]
- Binary search
- $O(\log n)$ running time for n triangles!

Sample point: Random linear combination

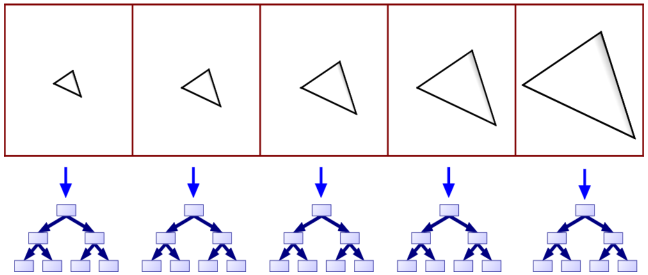
Improvements

Performance

Handling of large triangles:

- Projected area:
  triangle area $\times$ *projection factor*
- Classification by unprojected area
- Rasterize large triangles with z-buffer hardware

additional classification by triangle area:



Sample caching:

- Cache samples in spatial hierarchy nodes
- Speedup of up to factor 10
- Realtime performance on PC-hardware

Enhanced Data Structure

Dynamic modifications:

- Substitute dynamic search tree for distribution lists
- Insertion, deletion, modification in $O(h)$ (h = height of the spatial octree)

Efficient storage of highly complex scenes:

- Scene-graph based instantiation
- Storage $O(|SG|)$ instead of $O(n)$, $|SG|$ = size of scene graph

Example Renderings

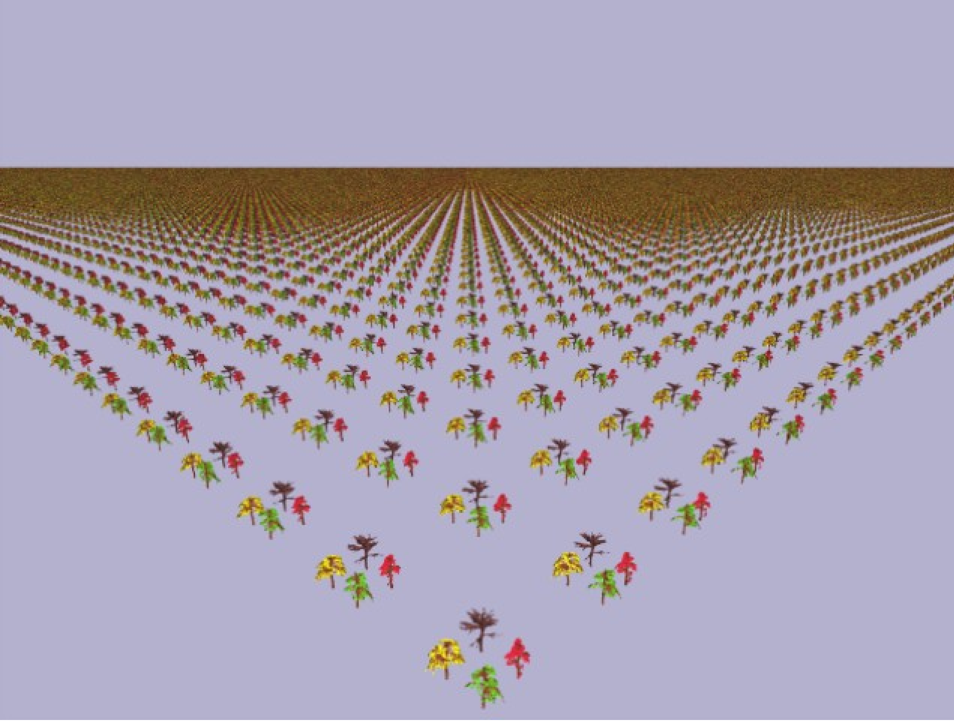
Example: Landscape

diffuse lighting, splatting (d=2),
sample caching,

Phong lighting,
per pixel reconstruction,
rendering time: 19.2 sec

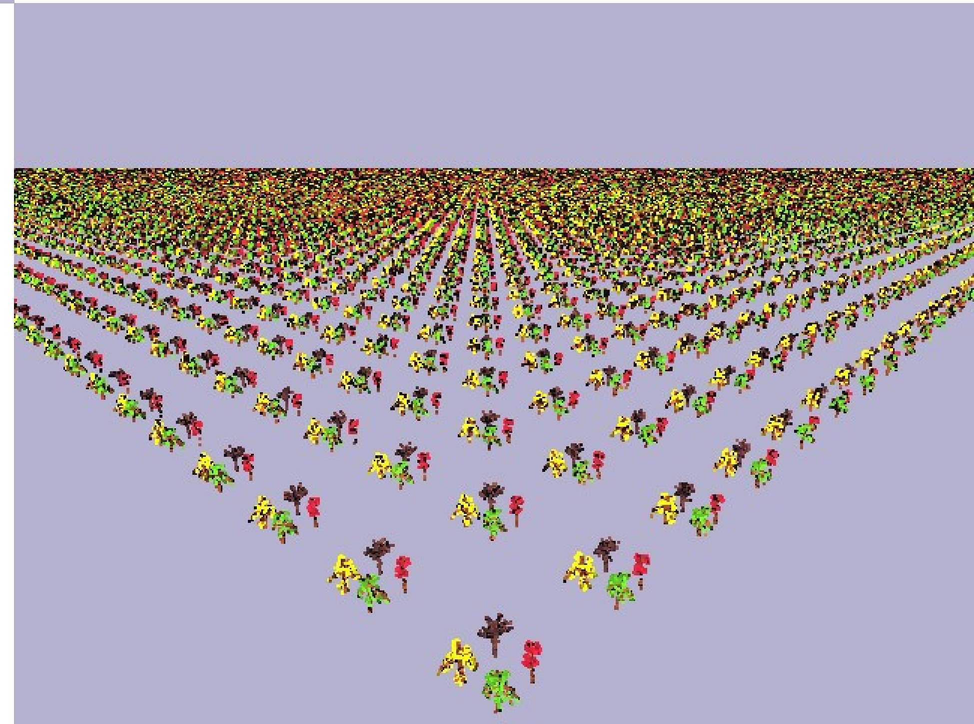
Complexity: 400 million triangles

Example: Forrest Scene



splatting, $d = 2$,
sample caching,
rendering time: 0.41 sec

Gaussian reconstruction,
rendering time: 120 sec



Complexity: 10^{14} triangles

Hardware: 800Mhz PC,

Future Work

Future Work

Future Directions:

- More efficient antialiasing
- Occlusion culling
- Modeling techniques for highly complex scenes
- Global illumination